Improving reliability and resilience of electric power distribution by cost-effective undergrounding and high-performance maintenance technologies

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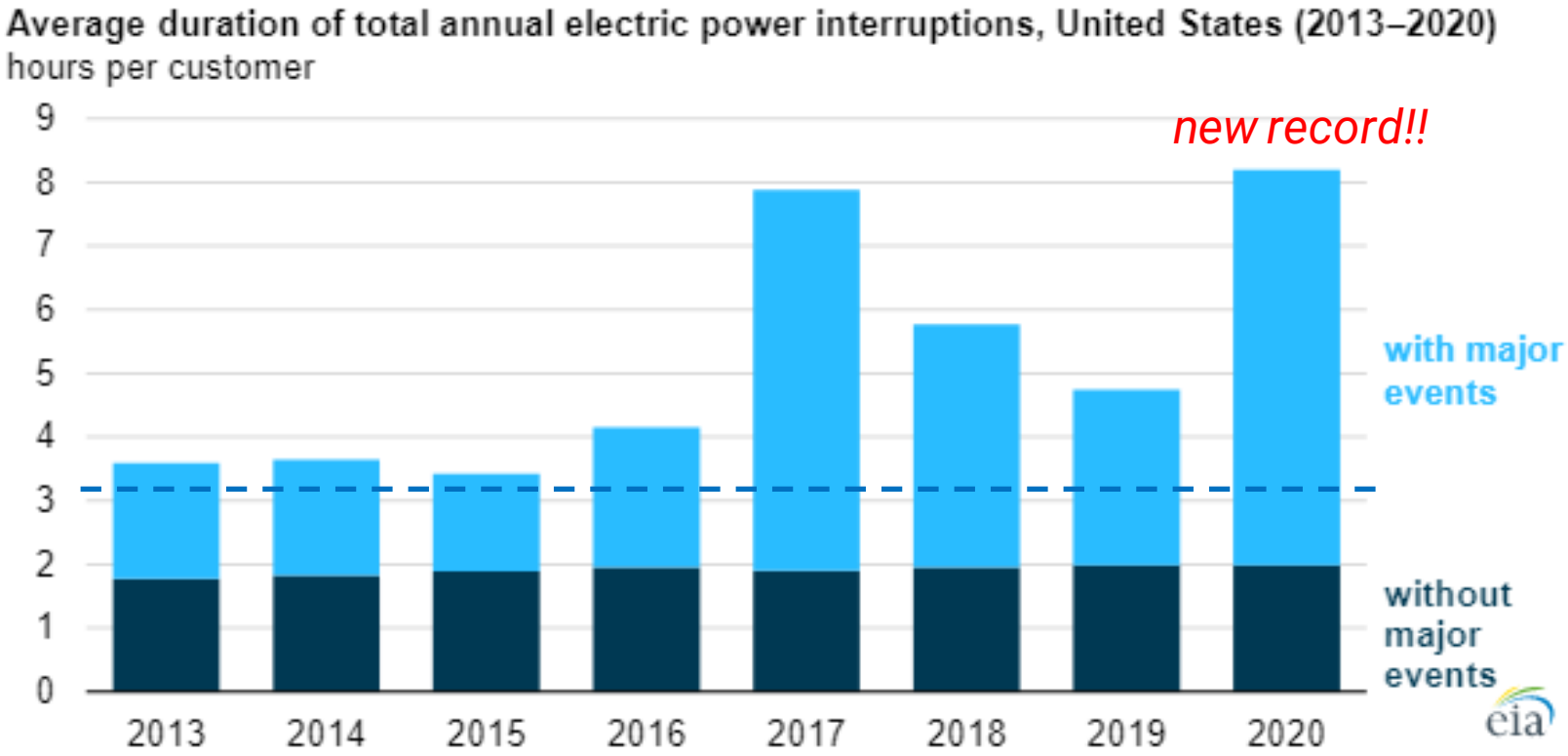
US SAIDI is steadily going up – the problem we are trying to solve



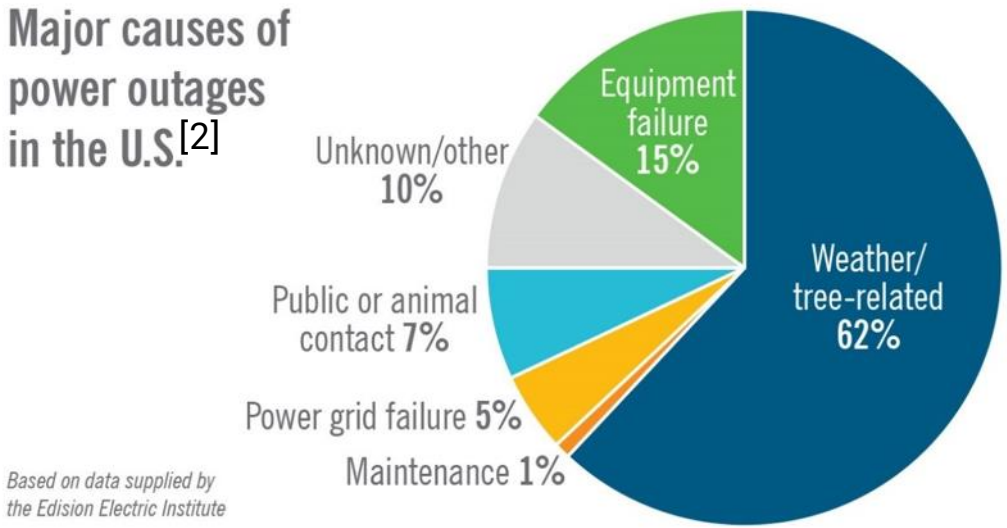
$$SAIDI = \frac{\text{sum of all customer interruption durations}}{\text{total no. of customers served}}$$ (System Average Interruption Duration Index)

- US Power outages from severe weather have doubled in 20 years
- 32,562 power line-ignited wildfires (1992-2020)

https://insideclimatenews.org/news/11072022/is-burying-power-lines-fire-prevention-magic-or-magical-thinking/

Majority of power outage happens at distribution (MVAC, 4-35 kV)

- 94% (SAI**DI**, interruption duration) and 92% (SAI**FI**, interruption frequency) are from distribution[1]



- cost of reliability ranging from **$150 to $400 billion/year**[3]

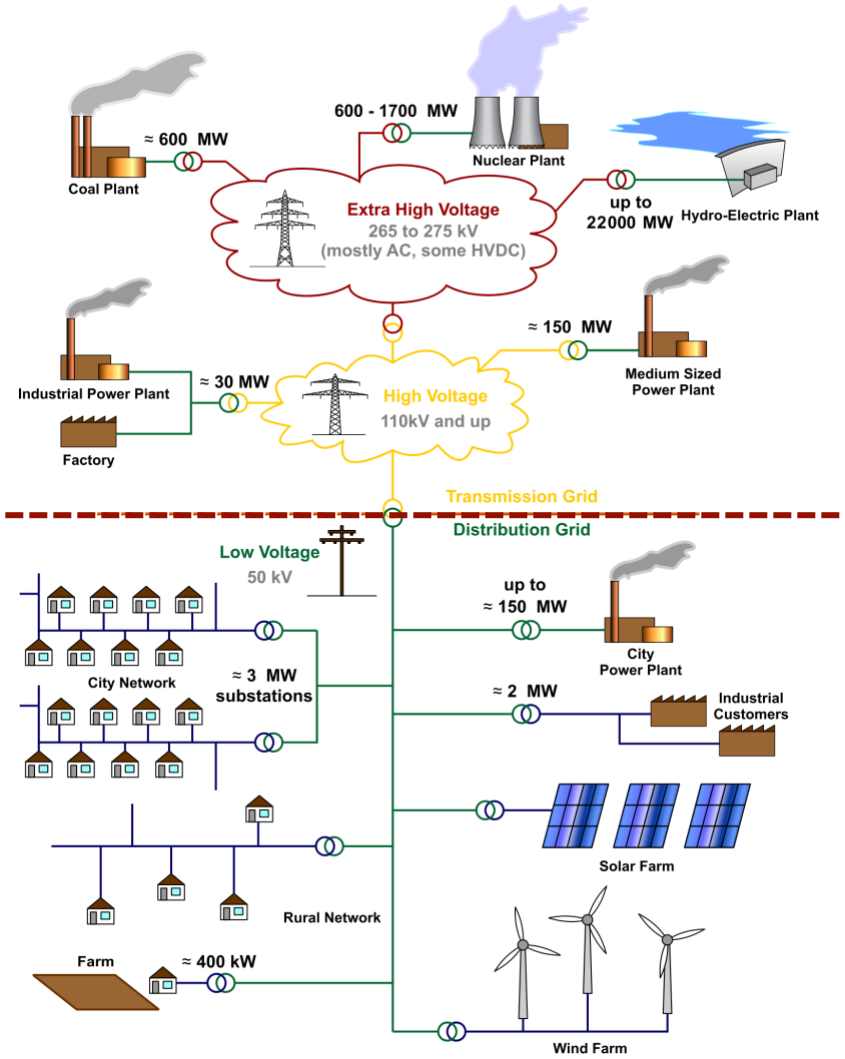
~600,000 mile

Transmission

Distribution

>5,500,000 mile

180 million power poles



[1] 2014 data, "Distribution system vs. bulk power system: identifying the source of electric service interruptions in the US" *IET Gener. Transm. Distrib.*, 2019, 13(5) 717-723
[2] Duke Energy, https://sustainablesolutions.duke-energy.com/resources/resiliency-plan/
(Data source: Out of Sight, Out of Mind – An Updated Study on the Undergrounding Of Overhead Power Lines (2012) Edison Electricity Institute)
[3] "Cost of Power Interruptions to Electricity Consumers in the United States (U.S.)" LBNL-58164 (2006)
[4] T&D line length: https://www.eei.org/issuesandpolicy/transmission/Pages/default.aspx & https://www.nae.edu/File.aspx?id=183084

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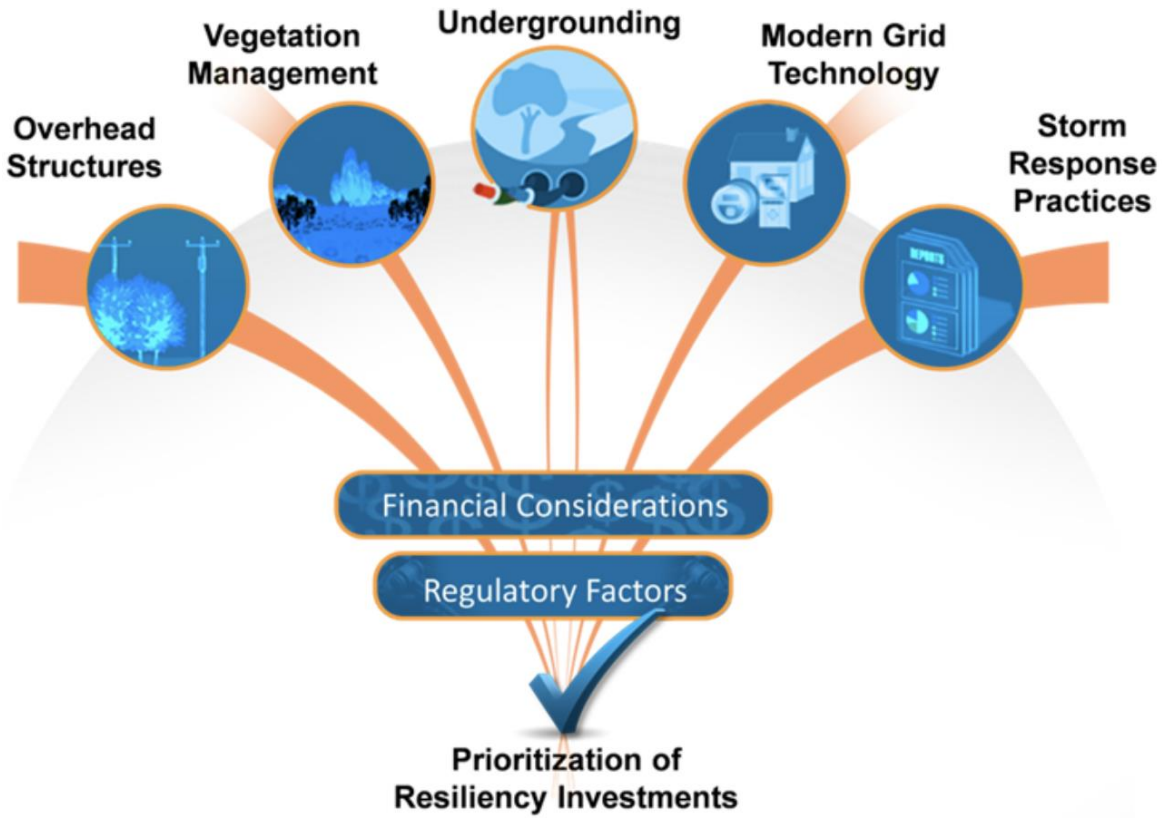
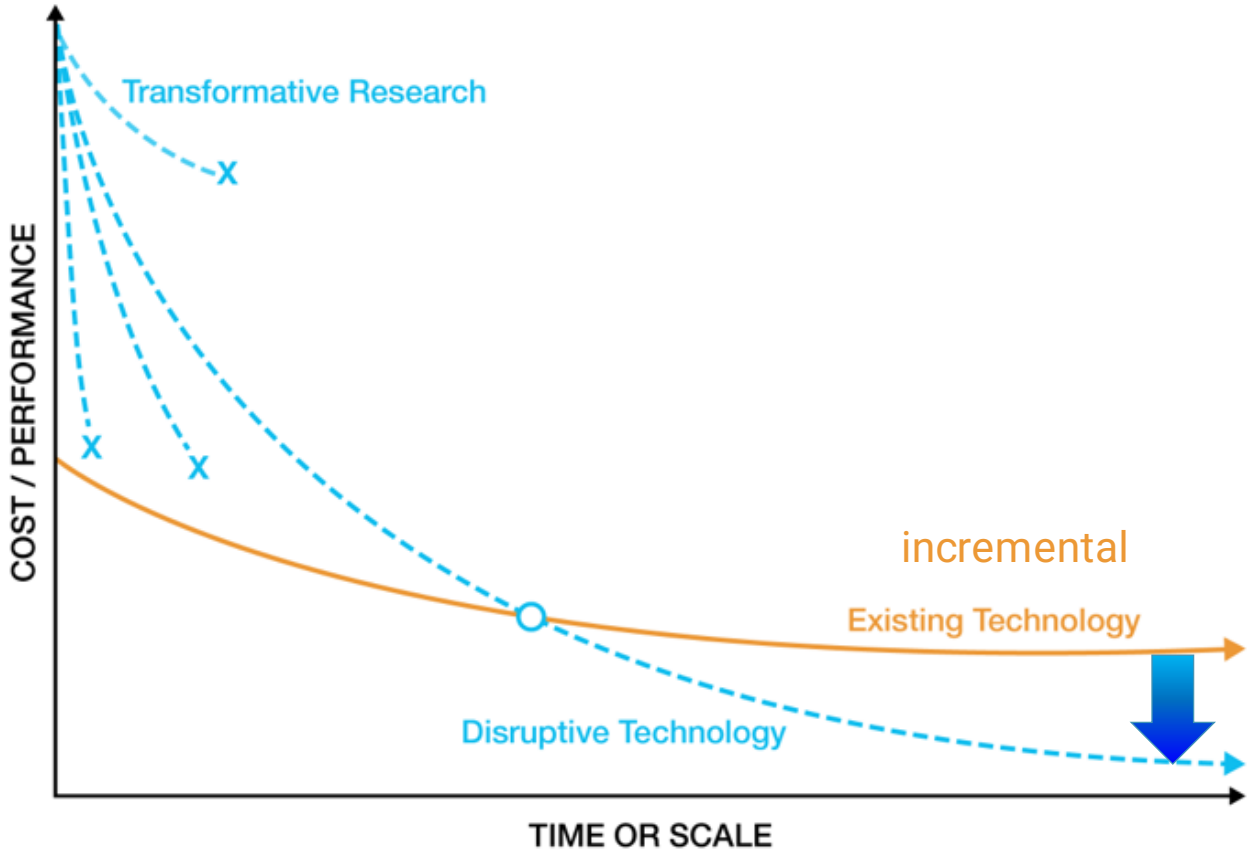
Why undergrounding? - high performance but difficult to employ

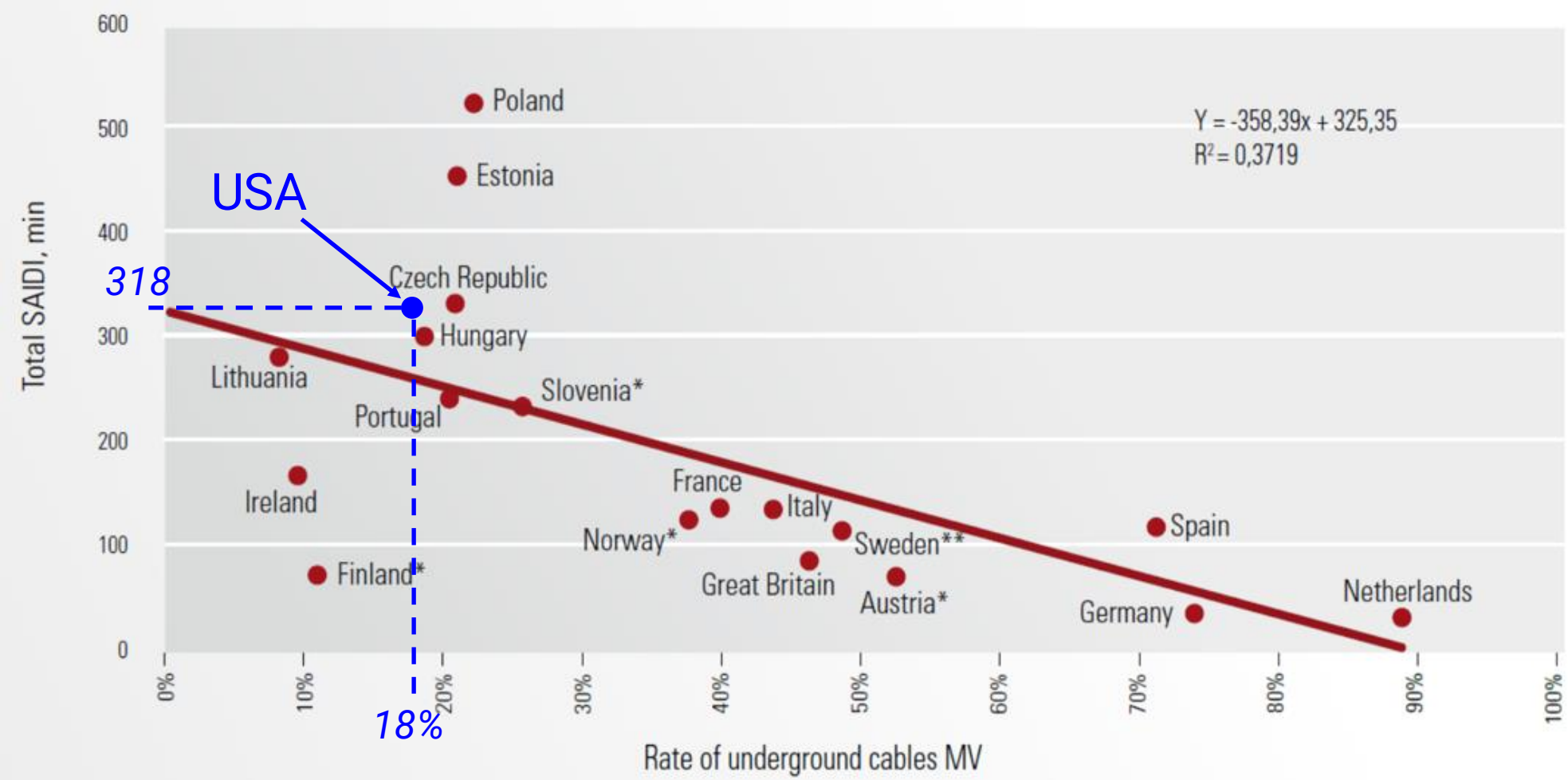




Undergrounding can reduce storm SAIDI/SAIFI up to 64-67%[1]

[1] Distribution Grid Resilience Technologies (EPRI report, 2015)
[2] Full study by Council of European Energy Regulators (CEER) - Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply (2018)
https://www.ceer.eu/documents/104400/-/-/963153e6-2f42-78eb-22a4-06f1552dd34c

Undergrounding power lines is a proven way to improve reliability



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Benchmarking of Reliability: North American and European Experience, J. McDaniel, W. Friedl, H. Caswell, 23rd International Conference on Electricity Distribution, 2015

Barriers to undergrounding power distribution infrastructure

- Too high upfront **cost**
  - Up to 10x higher cost than overhead
  - Shorter lifespan (20-30 years) than overhead (>50 years)
  - Too much work to get PUC approval, rate hike
  - This view is changing with life cycle cost comparison and reliability consideration
    - ➢ Transformative technologies to reduce upfront cost and increase life cycle?

- Shifted **risk** with underground assets
  - Safety concerns for operation and maintenance
  - Not visible and difficult to maintain and locate fault
  - Difficulty in quickly restoring the power
  - New kind of risks that operators are not familiar
    - ➢ Transformative technologies to improve operational safety and reliability?

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Program development - RFI questions category

Q1. Technology prioritization

- What are the major barriers to wide adoption of undergrounding?
- Cost reduction – what moves the needle the most?
- Which of the technology categories should ARPA-E prioritize and why?

cost

Q2. Reduce the cost of UG construction (construction technologies for borehole, conduits, vaults)

Q3. Improve sensing and awareness of UG infrastructure (detecting buried utilities)

Q4. Reduce errors in UG installation (cable splice and such)

risk

Q5. Incorporate health diagnostics, prognostics, and fault location

Q6. Identify/develop repair technologies (fast, minimal surface disruption)

Q7. T2M

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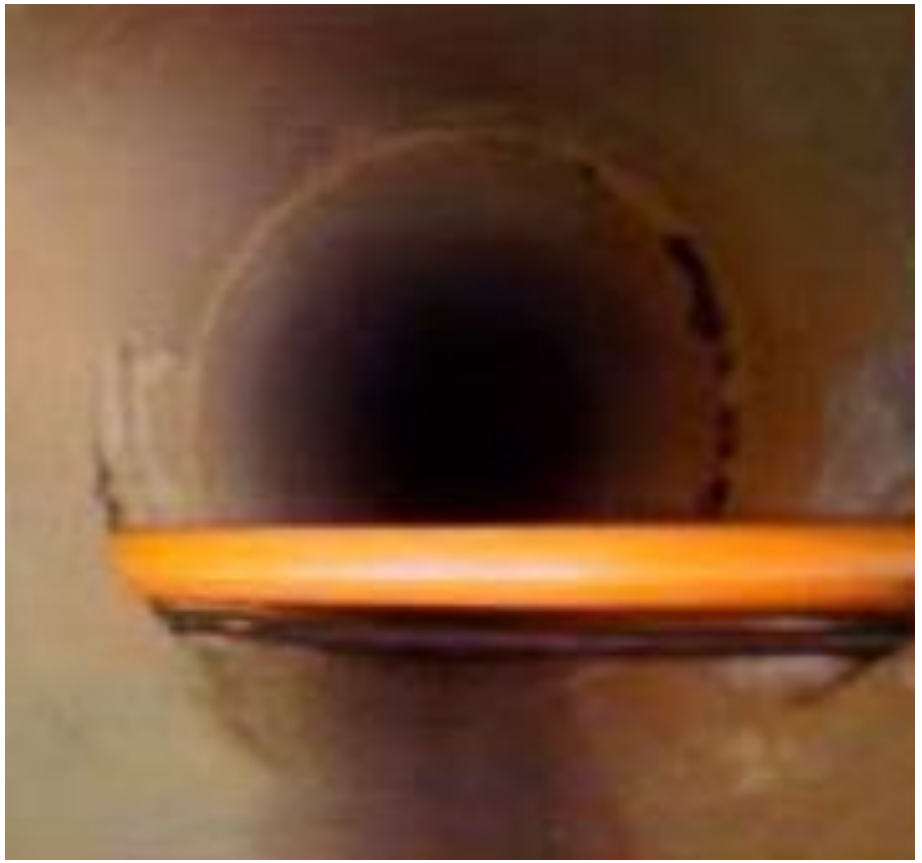
avg. 4-5 crossbores per mile
112,917 strikes in 2010 alone (mostly HDD)
up to $100M cost per a crossbore event



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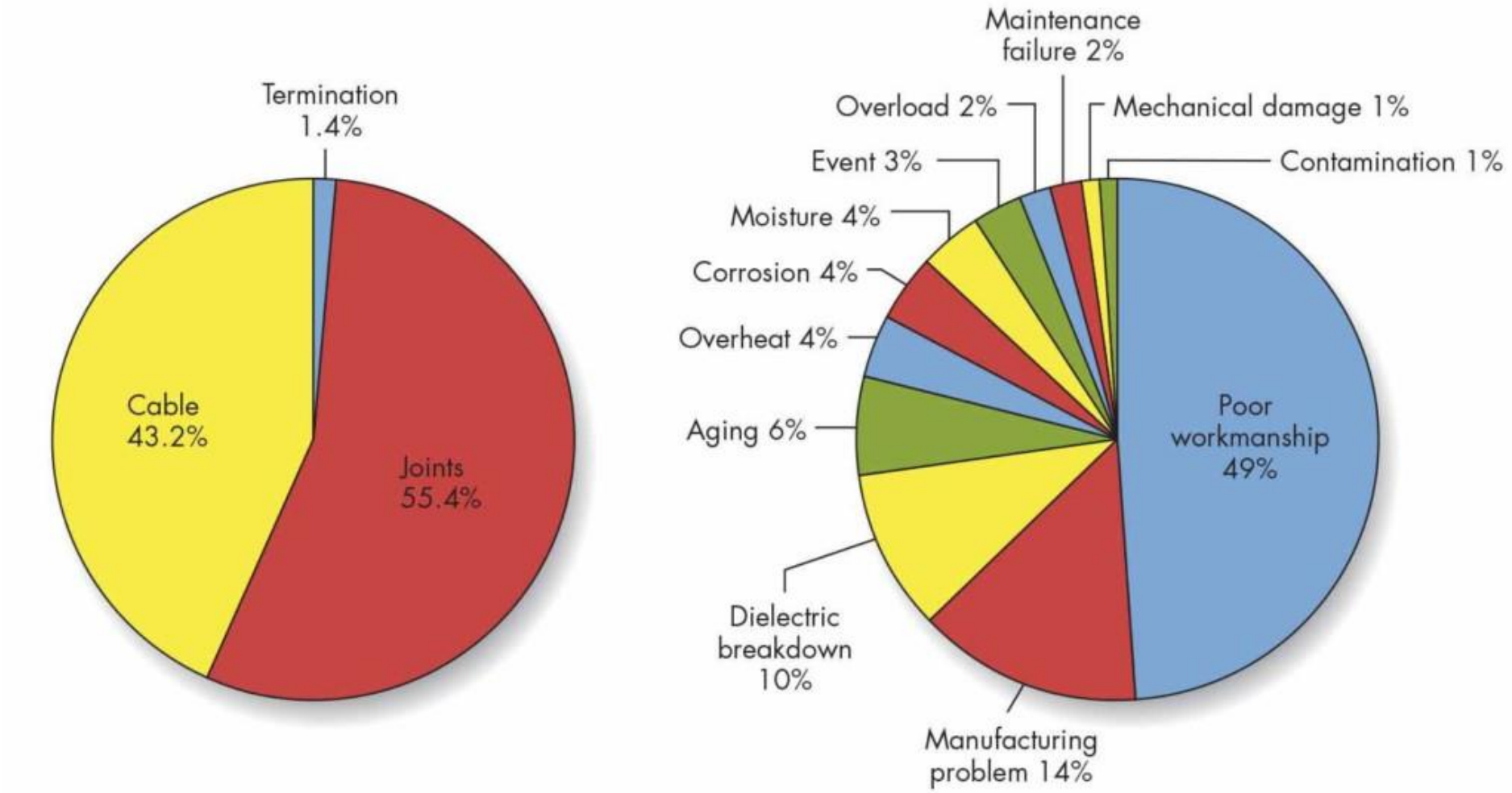
Component failure modes and root causes (MV cable)



https://netaworldjournal.org/partial-discharge-tests-for-medium-voltage-power-cable-systems/

External inputs (green box = contributed to RFI)

26 written responses
many 'team' responses
(as of April 6th)

Industry

Prysmian Group
THE BORING COMPANY
GE Research
Baker Hughes
MELNI Quality That Connects
ULC TECHNOLOGIES
MICHELS
Amphenol
AEGION Stronger. Safer. Infrastructure.
Meta
LIVEWIRE INNOVATION
Southwire
PETRA
FORO ENERGY
MAINSTREAM ENGINEERING
J.D.Hair&Associates,Inc. Consulting Engineers | Tulsa, OK
Direct Connect
A TO B PUBLISHING INC.
360ENERGY Energy Excellence / Carbon Solutions
EATON Powering Business Worldwide
VEIR
earthgrid
IMCORP Power Cable Reliability
exodigo
Sentient ENERGY
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Gov./non-profit

NARUC National Association of Regulatory Utility Commissioners
NASEO National Association of State Energy Officials
DARPA
U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY
iSTT
EPRI ELECTRIC POWER RESEARCH INSTITUTE
NASTT
STATE OF CALIFORNIA ENERGY COMMISSION
CALIFORNIA ENERGY COMMISSION
UTC Washington Utilities and Transportation Commission
IEEE
MASSACHUSETTS CLEAN ENERGY CENTER
CBSA
NEW YORK STATE OF OPPORTUNITY. NYSERDA
EEI Edison Electric INSTITUTE
gti
U.S. Department of Transportation Federal Highway Administration
U-DIG UNDERGROUNDING DISTRIBUTION INTEREST GROUP
pdi2

Utilities/Co-ops

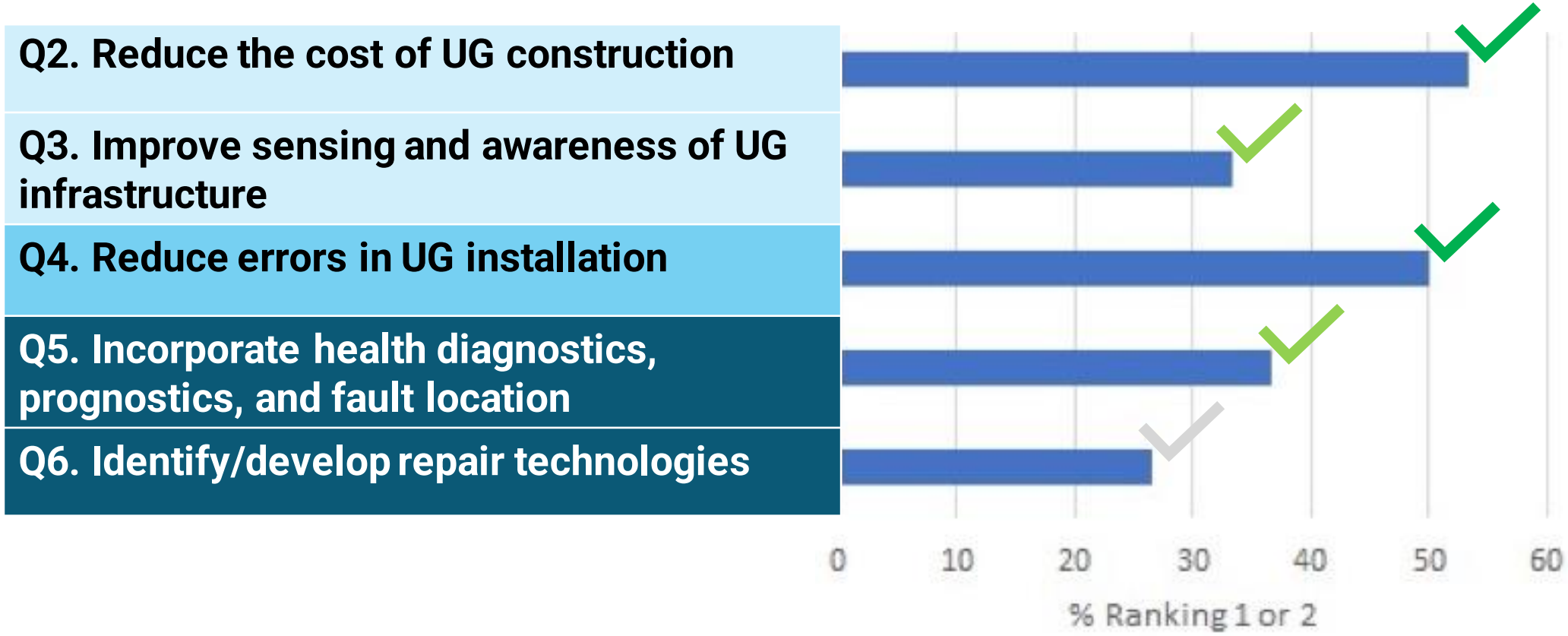
nationalgrid
BGE An Exelon Company
exelon
PG&E
FPL
conEdison
CITY ISLAND RISING
Alabama Power
SOUTHERN CALIFORNIA EDISON
DLC DUQUESNE LIGHT CO.
DC PLUG Making your electric system more resilient
pepco AN EXELON COMPANY
NEXTera ENERGY
Dominion Energy

Universities/Nat'l. Labs

COLORADO SCHOOL OF MINES
UNIVERSITY OF TORONTO
RICE UNIVERSITY
UC San Diego
YONSEI UNIVERSITY
Boulder
THE UNIVERSITY OF UTAH
THE UNIVERSITY OF TEXAS AT AUSTIN
ATM
FSU
UH
UNIVERSITY OF SOUTHERN QUEENSLAND
Pacific Northwest NATIONAL LABORATORY
NREL Transforming ENERGY
Sandia National Laboratories
OAK RIDGE National Laboratory
BERKELEY LAB

EPRI's U-DIG poll results (320 members/67 utilities) As of March 2022

Which of the following technology categories has the most potential impact on lowering the cost and improving reliability of UG power distribution?



special thanks to Dr. Drew McGuire & Dr. Joshua Perkel at EPRI

Proposed program strategy (pre-workshop)

Which of the following technology categories will meet ARPA-E criteria: "High-risk white space" and "If it works, will it matter?"

Full Program Technology Categories

Sub-topic of Q2

- Q2. Reduce the cost of UG construction
- Q3. Improve sensing and awareness of UG infrastructure
- Q4. Reduce errors in UG installation
- Q5. Incorporate health diagnostics, prognostics, and fault location
- ~~Q6. Identify/develop repair technologies~~

Technology categories for breakout discussions

Group A

Dr. Jack Lewnard
(Program Director)

Group C

Dr. Emily Yedinak
(Fellow)

Cost-effective, safe, and fast underground construction

Category 1.1

Underground survey and mapping

Category 1.2

Safer, efficient, reliable cable splicing

Category 2

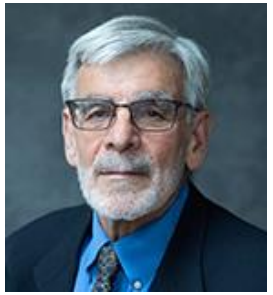
Fault prediction and location

Category 3

Group B

Dr. Bob Ledoux
(Program Director)

Group D



Dr. Dick O'Neil
(Senior Fellow)

Group E

Rakesh Radhakrishnan
(T2M Advisor)

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Technology categories for breakout discussions

Group A

Dr. Spencer Aertker
(tech SETA)

Group B

Dr. Sade Ruffin
(tech SETA)

Cost-effective, safe, and fast underground construction

Category 1.1

Underground survey and mapping

Category 1.2

Group C

Dr. Toni Marechaux
(tech SETA)

Group D

Dr. Kathleen Lentijo
(tech SETA)

Group E

Dr. Kalena Stovall
(tech SETA)

Safer, efficient, reliable cable splicing

Category 2

Fault prediction and location

Category 3

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DAY 1: Breakout Session #1 (Program scope/boundaries)

- Invited speaker presentations -> networking fast pitch -> B/O #1
- Five B/O groups with a mix of different stakeholders with same questions
- Questions for program scope
  - Identify technical white space and ‘ARPA hard’ R&D challenges
  - Prioritize key technology R&D areas
- Discuss program level goals, structure, and metrics
- ARPA-E staffs will facilitate the discussion to get your ”opinion”
- Report back on Day 2 (6 minutes/group)

DAY 2: Breakout Session 2 (Technical directions/metrics)

- DAY 1 recap -> B/O #1 report back -> B/O #2
- **Complete the polls by EOD today**

- Five B/O groups of similar interest (+ utility companies in each group)
- Promote transformative, out-of-the-box ideas
- Specific boundary conditions will also be discussed
- We'll not prescribe the solutions/approaches
- Discuss 'how to test' different ideas objectively

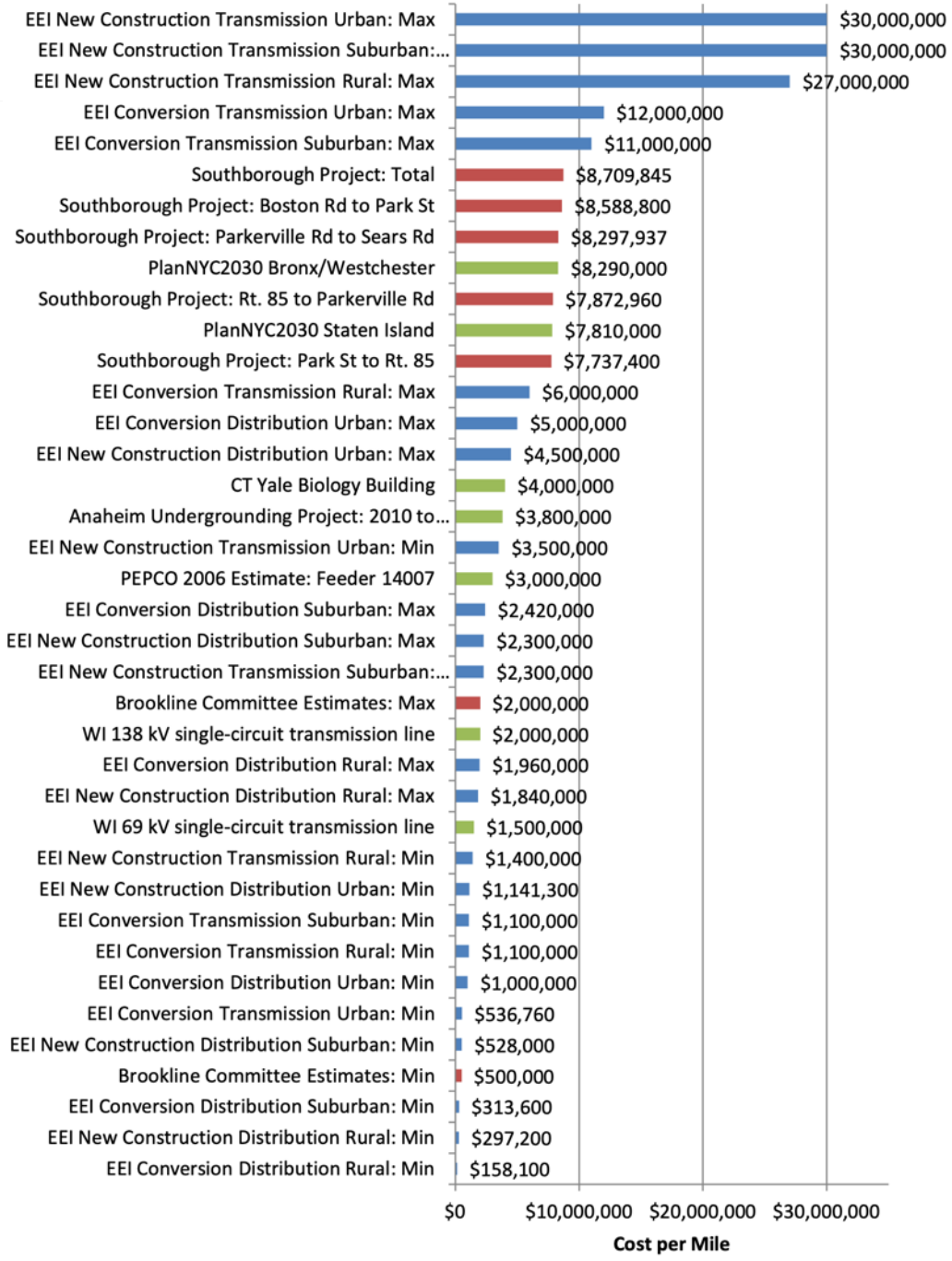
Undergrounding is a problem of diverse scenarios

A fixed cost target may not work

FEASIBILITY STUDY FOR UNDERGROUNDING ELECTRIC DISTRIBUTION LINES IN MASSACHUSETTS

December, 2014

Table 2: Underground Cost Estimates from Various Reports



Why would potential program outcomes matter even more?

- Decarbonization by electrification, adoption of more renewable power generation, and de-centralization of energy systems will drive the need for more localized distribution grid infrastructure

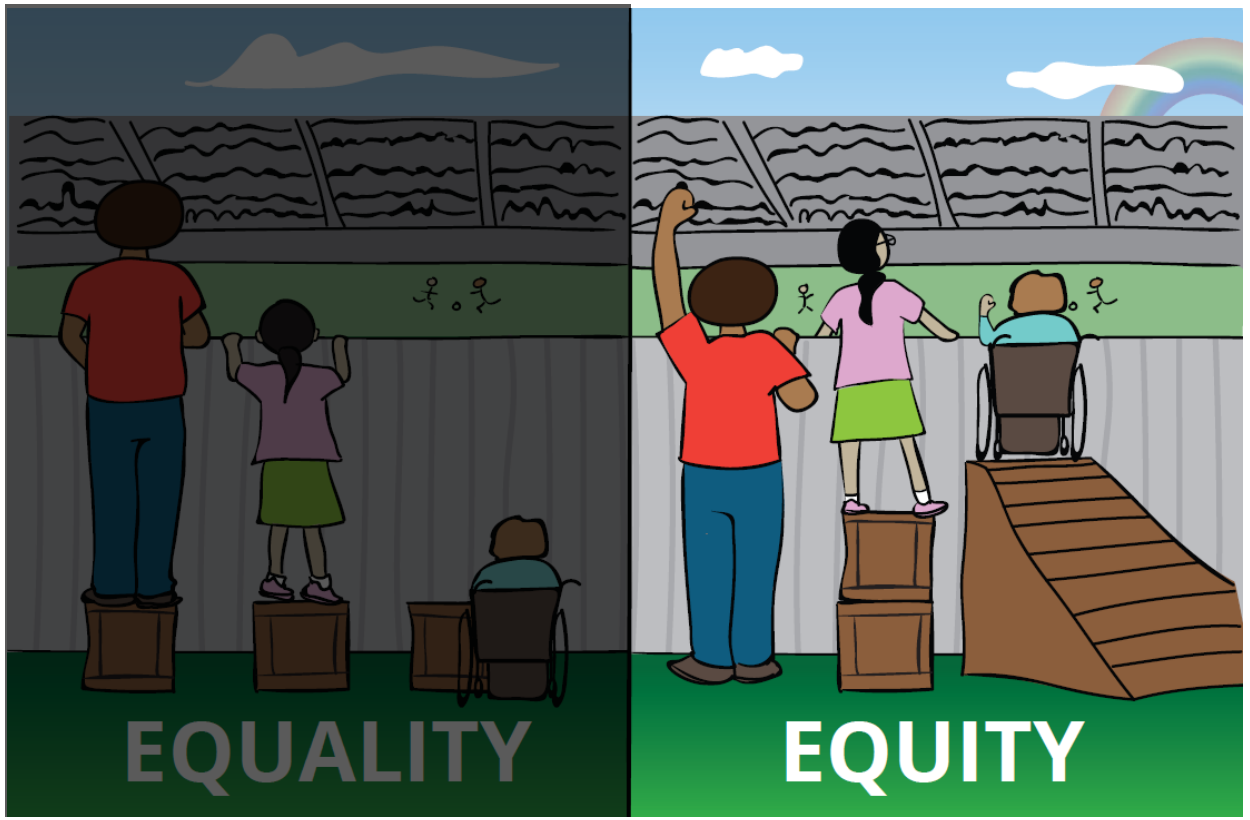
- Where do we put these new infrastructure? overhead or underground?
- ...and other infrastructure? (water, gas, broadband, CO_2 pipeline, H_2 pipeline)

- However, it is extremely costly and slow to underground power lines today even for just 5-10% of conversion or expansion (except for greenfield)

- Need both cost-effective and speedy methods

Both planned (Public Safety Power Shutoffs) and unplanned outages disproportionately affect Low-income Communities

Fair and Equitable Solutions?



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Workshop guidelines and rules

- Workshop goal is NOT reaching a consensus nor making a decision
- ARPA-E wants to gather inputs and opinions from all of you
- Ask many questions after speaker presentations
- Be actively engaged during B/O sessions (your opinion matters!)

- Break the ice and get to know each other!
- Introduce (fast pitch and more) and network
- Look for potential partners
- Request follow up meetings
  - one-on-one meetings are possible right after the workshop (except for 3-4 pm)

The laws of physics still apply, but erase the 'box' around your thinking and have fun!

https://arpa-e.energy.gov